

ADVANCED TECHNOLOGY: 1-1 IS AVAILABLE AT JPL

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The Jet Propulsion Laboratory (JPL) of the California Institute of Technology is a Federally Funded Research and Development Center (FFRDC) located in the foothills above Pasadena. JPL operates under a contract between Caltech and the National Aeronautics and Space Administration (NASA), whereby Caltech staffs and operates the Laboratory in performing its NASA designated role as the lead center for the unmanned exploration of the solar system - and beyond. Current staffing is approximately 5500 - all Caltech employees - with an annual budget over one billion dollars.

Explicit in the Caltech/NASA contract is a provision authorizing that up to a quarter of JPL's work-years' effort may be applied to non-NASA oriented activities. This reflects a joint NASA/Caltech philosophy that the techniques and technologies developed to support the unmanned planetary exploration program - all at public expense - may have applications in other areas, and a concerted effort should be made to investigate such opportunities. These non-NASA activities are the province of the JPL Technology and Applications Programs Directorate, and include working relationships with industry, academia, and other government agencies. Within this [directorate, the JPL Undersea Technology Program endeavors to apply and transfer these capabilities to the area of underwater research and operations,

The operational requirements of unmanned space exploration bear striking similarities to those imposed by operations in and on the oceans. We are faced with the development and operation of sophisticated, extremely reliable vehicles, operating unattended for periods measured in years, in remote locations, in unknown and often hazardous environments, and with rigid constraints on weight, size, power and - increasingly - costs. Within these constraints, it is desired to maximize the sensor

complement and information return, often over bandwidth limited channels. These same requirements and constraints must sound very familiar to those operating in the oceans, particularly with ROV's and AUV's.

Because of the extreme distances involved in planetary exploration, and the consequent long delays in communication times, planetary spacecraft of necessity must rely heavily on intelligent and autonomous onboard systems. One advantage we may have over marine operators is that we don't worry about losing our vehicle - once it's launched, we KNOW we're not going to get it back!

This inability to retrieve our vehicles, however, does place extreme emphasis on quality control, and component and system functional reliability. Successful missions have depended on the development of techniques and technologies to assure that things work - unattended - for very long periods of time. The two Voyager spacecraft, launched in 1977, have explored all the planets in the outer solar system - except Pluto - and are now exiting the solar system and trying to detect the galactic interface. They are still operational, and we remain in communication with them - at distances of five to six billion miles - via their on-board 25 watt transmitters!

Of significant interest in space - and ocean - operations is the trend toward miniaturization. Currently at JPL, the Cassini spacecraft is being assembled; it will be launched about a year from now and will proceed to Saturn on a 7 year VVEJGA (Venus, Venus, Earth, Jupiter Gravity Assist) trajectory, where it will go into ever changing orbits for a design period of four years, exploring the planet and its satellite system and discharging a probe into the atmosphere of Titan. The spacecraft is about three stories high, weighs about 5 tons, and carries the most extensive and sophisticated set of instruments ever flown. It is also a billion dollar project. Missions on that scale, and perhaps launched only once in a decade, are no longer affordable or desirable - nor are they necessary. The emphasis is on smaller, lighter, lower powered, and cheaper vehicles.

JPL's Space Microelectronics Program is developing the technology to satisfy all of those criteria. Fig. 1 shows a comparison or progression (downsizing) from Cassini to a possible micro-spacecraft of the future, utilizing a variety of the JPL developed micro-sensors and associated technology. This effort has produced a number of miniature sensor packages, including, for example: accelerometers, seismometers, radiometers, hygrometers. A hydrophone developed for the Navy is encapsulated in a 1 inch sphere. (Fig. 2). In addition to small size, these devices exhibit extreme sensitivity, ruggedness, and very low power consumption.

Of particular interest may be a Reversed Electron Attachment Detector (READ). It is a man-portable device capable of unambiguous detection of unique chemical signatures associated with mines. READ has demonstrated the ability to detect 2,4-DNT; 2,4,6-TNT; PETN; and RDX in parts per trillion concentrations, as well as nerve and blister agents and non-conventional explosives such as perchloro and peroxy compounds.

Utilizing complementary metal-oxide semi-conductor (CMOS) technology, JPL has developed a new imaging sensor - virtually a camera on a chip - promising smaller and cheaper imaging systems but comparable in performance to the current state of the art (Fig. 3). This active pixel sensor technique represents a considerable leap beyond the widely used charged coupled device (CCD) technology. Use of the CMOS sensors presents the opportunity for reducing imaging costs, power and size, and improving reliability.

The thrust toward miniaturization places a concomitant need for improved power sources. The Laboratory has an extensive effort devoted to advanced power sources featuring small size, long life and increased specific energy. In the range up to 100kW and specific energies to over 200 watt-hours/kg, Fig. 4 shows a number of cell types under consideration, development and test. An "AA" LiTiS_2 cell has been successfully cycled 1,000 times to 50% discharge at ambient temperature. Also under development

(Fig.) is a direct methanol, liquid feed fuel cell where a 3% methanol/water mixture is the fuel and air is the oxidant. Advantages include simplicity, start up at room temperature, operation at 70°C to 90°C, and no resulting pollutants, the only output being potable water. The system is modular, with a 4 x 6 inch cell providing 50 amperes continuously at 0.4 volt, at 90°C with air. Plan is to demonstrate a 1 kW fuel cell stack next year.

In addition to the above, other JPL technologies which merit investigation for marine applications, include - but are not necessarily limited to: teleoperators/robotics; roving vehicles; communications; data collection, processing compression; digital imaging and visualization; guidance, control, navigation; anti certainly quality control and systems integration.

Teleoperator/robotic activities range in size and function from a large, seven-degree of freedom arm being developed for NASA use as an autonomous surface inspection device for the Space Station, to a micro-surgery device for medical applications, e.g., inside the eyeball surgery. The NASA arm incorporates an eddy current sensor for detection of minute pits or cracks, as well as a proximity sensor to avoid actual contact with the surface. The micro-surgery device is being developed in conjunction with an eye surgeon, and has an accuracy/repeatability of ten angstroms. The device will also eliminate any tremors resident in the surgeon's hands, even his pulse beat. Also in the laboratory is a modular, eleven degree of freedom arm, about 2 inches in diameter, which permits access into intricate, complex passages.

An autonomous roving vehicle, "Sojourner" (Fig.), will be mounted inside the "Pathfinder" spacecraft, which will be launched this coming December and will land on the surface of Mars on July 4, 1997. After landing, "Pathfinder" will unfold and deploy the rover onto the surface of Mars. It will be directed to explore certain targets or areas, navigating on its own, and performing engineering and scientific experiments. "Sojourner" will transmit its information to the lander for re-transmission back to earth. The rover's

prime power, ~~16~~ ¹⁶ watts, is provided by a 0.2 square meter solar panel, backed up and augmented by lithium sodium di-oxide "D" cells.

New autonomous control and data processing methodologies are being developed which can be applied to underwater target detection, where transmitted pulse sequences form a non-Gaussian process in the presence of ambient/environmental noise. Using these statistical techniques with inherently efficient algorithms for emerging parallel computational architectures (e.g. systolic arrays, neural networks) will result in effective "near optimal" algorithms for high performance, real-time underwater signal and target detection, identification and tracking. Additionally, the autonomous control methods will enable unmanned underwater maneuvering with complete failure detection, identification and recovery capability.

Because of the crippled 16 foot diameter high-gain antenna on the Galileo Jupiter orbiting spacecraft, communications have had to rely on the much smaller low-gain antenna, with a consequent decrease in transmission rates from an expected 135 kbs to less than 2 kbs. To compensate, JPL communications researchers have devised methods to extract the maximum amount of information from this abridged data stream. The technique is described as a "feature driven data compression technique for bandwidth critical applications". Since underwater transmissions are typically bandwidth critical, this approach may offer increased information transmission over a given bandwidth.

Underway at JPL is a 3-year technology demonstration program, MUDSS" (Mobile Underwater Debris Survey System) funded by the Strategic Environmental Research and Development Program (SERDP) in the Cleanup thrust area. Its purpose is to demonstrate technologies necessary to successfully survey underwater "formerly used defense sites"(FUDS) for ordnance and explosive waste (OEW). The program is a joint Department of the Navy and NASA effort being executed by the Naval Sea Systems Command's Naval Surface Warfare Center (NSWC), Dahlgren Division, and the Jet

Propulsion Laboratory. The first year of the effort was completed in 1995, to (1) demonstrate that a prototype MUDSS sensor suite shows good promise against inert OEW targets, and (2) provide a multi-sensor data base to be used during Phase II to refine processing algorithms prior to at-sea testing at actual FUDS.

The foregoing provides a brief and necessarily limited introduction to several of the existing technologies which it is felt have application to areas of your interest. Far from satisfying your curiosity, it is hoped that this exposition will serve to arouse your interest and provide motivation to explore further. From our standpoint, the preferred follow-up would be to have you personally visit the Laboratory, which would serve two purposes: (1) it would afford you the opportunity to see hardware and discuss these and other technologies first hand with those directly involved, and (2) it would provide us your assessment of these technologies and advice as to the direction for future developments. It is a win - win situation!

The Consortium for Oceanographic Research and Education, CORE, undertook an Interagency Partnership Initiative to "reexamine our Nation's posture toward ocean science and technology and establish a new and invigorated partnership concept". The Initiative produced "Oceans 2000: Bridging the Millennia -- Partnerships for Stakeholders in the Oceans". Among its recommendations were: (1) define specific research and education partnership opportunities for academia, industry, and the Federal Government, and (2) develop an integrated partnership management plan to provide effective and cost efficient federally funded ocean science and technology programs.

The 1992 ocean Studies Board Report, "oceanography in the Next Decade: Building New Partnerships", in commenting on such partnerships, stated: "In general, partnerships must be extended beyond financial relationships to include the sharing of intellect, experience, data, instrument development, facilities, and labor".

In his keynote address at the JPL Undersea Technology Symposium in May of this year, RADM (Ret) Brad Mooney reviewed preliminary results of the Marine Board Study,

"Undersea Vehicles and National Needs". He stated, "An increased role for AUV's is anticipated in all of the areas I've mentioned. AUV's will require the most technological advances for them to be competitive, efficient, and effective, but they promise great payoffs in capabilities as sensors, communications, and control techniques are improved".

The sentiments expressed in the previous three paragraphs are typical of current thinking and reflect an awareness of the stringent budgetary constraints faced by all, and the consequent need to conserve resources and use capabilities wherever they may reside. We at the Jet Propulsion Laboratory invite and encourage your investigation of our capabilities as potential resources for your use.

As Dr. Don Walsh commented in an article in the April issue of "Sea'1 ethnology", when referring to the JPL Undersea 1 ethnology Program: "A model that right now produces bought-and-paid-for technologies that can be adapted to ocean research and business. TAKE ADVANTAGE! THE PRICE IS RIGHT!"

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